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THE INFLUENCE OF LOCAL LAND USE ON THE WATER QUALITY OF URBAN RIVERS

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ABSTRACT: Urban river flows are often highly variable and extremely polluted, which limits their potential for recreational use and as habitat for terrestrial and aquatic organisms. This study investigates how different urban landuses are reflected in the water quality of a specific river. To accomplish this, the study adopts a longitudinal approach and assesses water quality at multiple points along a single system that has three distinct land uses: 1) rural and agricultural; 2) residential; and 3) industrial. The study shows that water quality is relatively good in the rural and agricultural region, shows signs of impairment in the residential region, and becomes heavily impaired in the industrial region—despite having very similar stream side environments (good riparian vegetation cover and a floodway reserve) for its entire length. This study identifies which portions of the catchment are most responsible for non-point source pollution in urban rivers and therefore can be used to target remediation strategies to help improve the overall quality of these systems.

Keywords: Non-point Source Pollution; Nutrient Pollution; Heavy Metals; River Management

1. INTRODUCTION

Urban rivers are major assets to communities as they provide numerous benefits, including fresh water, recreation, landscape amenity, habitat provision and flood control. Humans have long recognized the value of urban rivers, with most human settlements having been established along riverbanks [1]. However, as cities grow their associated rivers can experience changes to their ecosystems as a consequence of pollutants that originate in the urban environment. This leads to a degradation of stream ecological functioning and the loss of other river resource amenities. To mitigate these problems, numerous regulations and initiatives have been enacted at local and national scales to protect urban rivers [2]. Despite these, urban river pollution and degradation continue to be a problem worldwide.

Urban river water quality is mainly affected by human activities that either directly modify stream form and/or function or introduce pollutants into the stream. In terms of pollutants, these may arrive in the stream from either “point” or “non-point” sources. Point source pollution can be attributed to one specific cause and as such tends to be more easily managed (i.e., if the point source can be identified the pollution can be eliminated or reduced through direct action) while non-point source pollution derives from catchment runoff, and as such is highly dispersed and largely untraceable. This aspect of non-point source pollution makes it much more difficult to manage [3]. According to an investigation by [4] non-point source pollution from agriculture, forests and developed urban areas contributes around 74-75% of nitrogen and 80-82% of phosphorous to total pollution loadings in rivers. This demonstrates how difficult it can be to eliminate these pollutants, as the sources are distributed and hard to manage while their contribution to overall pollutant loads is very high. Another example of the problems associated with non-point source pollution can be found in research by [5]. They showed that the main causes of urban river pollution were the discharge of non-point source industrial and agricultural wastes and domestic sewage (such as people and livestock excrement) throughout the watershed. Such pollutants typically alter the properties of urban rivers including their colour, odour, acidity and the ecosystems contained within them [6].

To combat these problems, both monitoring and mitigation (i.e., ensuring a certain level of water quality) need to be undertaken to maintain the ecological balance of urban rivers and to avoid any public health problems [7]. To achieve this, water quality is often monitored, using a variety of physical-chemical, chemical and biological indicators [8]. These indicators are then assessed to determine whether the observed levels reflect anthropogenic factors (which can be managed) or to natural processes such as erosion, climate, hydrological conditions, topography, catchment area, tectonic and or edaphic factors (which normally cannot be managed).

In addition to monitoring, there are some methods for enhancing the water quality of urban rivers (i.e., mitigation). For example, [9] show how employing wetlands in an urban river system can partially remove nutrients and other elements that affect the ecosystem of a river. Likewise, [10] show that vegetation improves and maintains waterways and that sites with good riparian vegetation typically have better water qualities than those lacking riparian vegetation. Thus, monitoring and mitigation are used in combination to improve the health of urban rivers.

To achieve the best outcomes for urban rivers, it is clear that further research needs to be done to determine where pollutants are coming from (e.g., how different land uses impact on the delivery of non-point source pollutants to adjacent waterways) and how different river configurations (e.g., natural and artificial streams; vegetated and non-vegetated riparian areas; parklands or urban flood corridors, etc.) affect water quality. This project aims to investigate these issues. Specific aims of the project include determining which land use types most impact on urban water quality and what affect, if any, stream and streamside form and character have on the quality of an urban stream.

2. SITE DESCRIPTION

Kororoit Creek is located in the city of Melbourne in the southern part of the state of Victoria, Australia (Fig. 1), originating in the rural foothills of the Great Divide near Gisborne and Sunbury. The river then flows into the western suburban areas of Melbourne.

A variety of animals, including fish, birds, mammals, amphibians and arthropods, make their homes in Kororoit Creek. For example, wetlands along the creek are home to the endangered Growling Grass Frog and remnant native grasslands in the lower sections of the river provide habitat for the endangered Striped Legless Lizard. There is also a large population of native water rats and significant remnant stands of saltmarsh and white mangroves in the lower sections of the river, which are used by a wide range of rare and/or endangered waterbirds. Thus, Kororoit Creek provides habitat for a diverse range of species, including many that are at risk of extinction.

3. METHODS

To establish how land use is affecting the water quality of Kororoit Creek a longitudinal study was conducted along the river’s length. Multiple field sites were investigated and compared with data from two long-term monitoring sites (Fig. 2). Thus, this study investigates two sources of data: 1) long term data collected by Melbourne Water at two sites along Kororoit Creek (low spatial but high temporal resolution data); and 2) field data collected at eight sites for this study (high spatial but low temporal resolution data). The original objective was to collect data from nine sites (Fig. 2) but there was insufficient flow at the uppermost site (Site 9) to enable analysis. Thus, only data from sites 1-8 are reported here. Sites 7-9 were located within a section of the catchment that was dominated by agricultural landuse. Sites 3-6 were located within a section of the catchment that was largely urban housing. Sites 1-2 were in an industrial sector of the catchment.

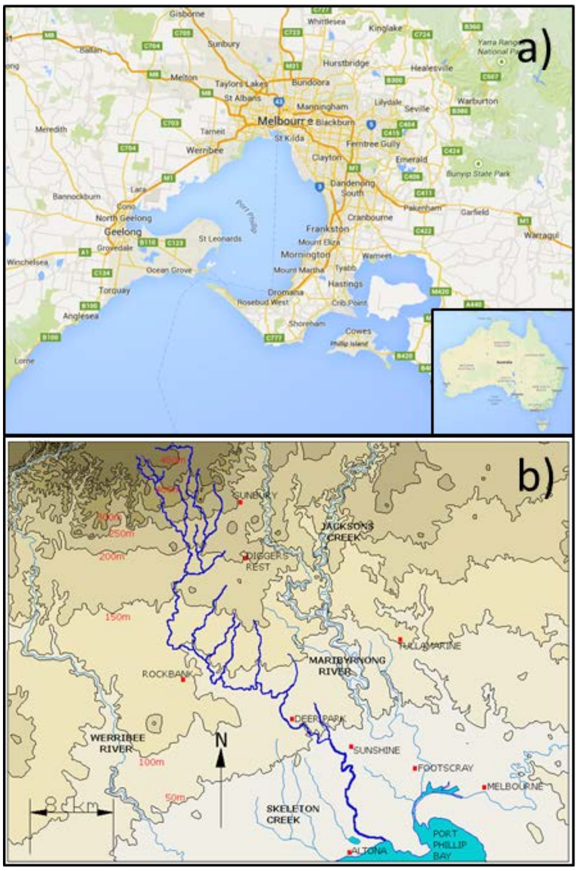

Fig. 1 The location of Kororoit Creek. a) the city of Melbourne, and its location within Australia (sourced from Google Maps); b) Kororoit Creek in western Melbourne (Sourced from Wikipedia).

Data were collected from the eight study sites between April 25, 2015 and May 10, 2015. In each case, a HI 9828 water quality multimeter (Hanna Instruments) was used to analyse the following variables: acidification (pH), turbidity (ppm), dissolved oxygen (%), and electrical conductivity (µS⁄cm).

Existing water quality data were also obtained for two Melbourne Water Sampling sites on Kororoit Creek that had been monitored since the early 1990’s (Fig. 2). These high quality, laboratory processed data included a wide range of water quality indicators, although they are limited in their spatial extent. The parameters available for these two sites from Melbourne Water include:

1. Ammonia (NH_3)
2. Total Nitrogen (N)
3. Total Phosphorus (P)
4. Dissolved Oxygen (DO) (%)
5. Electrical Conductivity (EC) $(\mu S/cm)$
6. Acidity (pH)
7. Escherichia Coli $(cfu/100ml$
8. Heavy Metals: *Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn).* (ppm)
9. Nitrate (NO_3)
10. Nitrite (NO_2)
11. Phosphate (PO_4)
12. Temperature (℃)
13. Suspended Solids (mg/L)
14. Turbidity (NTU)

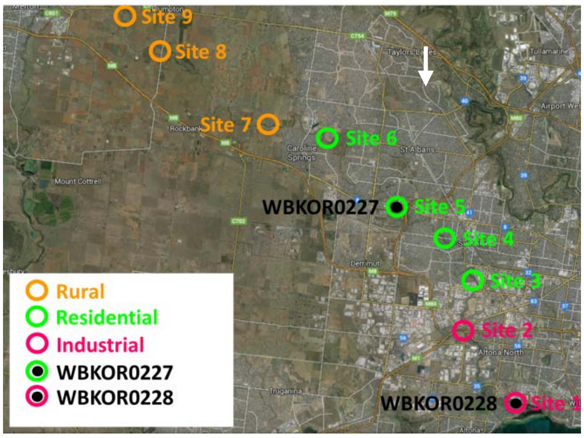

Fig. 2 The nine fields sites (sites 1-9) and two Melbourne Water monitoring sites (WBKOR0227 and WBKOR0278) assessed in this study (sourced from Apple Maps).

All data were analysed using simple graphical means. For the eight field sites, three samples were collected and the data from these were plotted against on the same graph to visually determine how water quality varied between sites and between sampling dates. The data for the two Melbourne Water monitoring sites were plotted together to ascertain how water quality at each site had changed through time and to illustrate which of the two sites had poorer water quality for the variable in question. Finally, the water quality data from both sources were compared to guideline values [11] to determine whether the water quality was deemed safe for each variable at each site and at each sampling time.

4. RESULTS AND DISCUSSION

This project investigated how land use impacts the water quality of urban rivers. The study included a wide range of water quality parameters and many of these showed at least some sensitivity to land use.

Standard water quality measures in urban environments include pH, total dissolved solids, dissolved oxygen and electrical conductivity. These standard parameters were measured at the eight field sampling sites and the results are presented in Fig. 3 and Table 1.

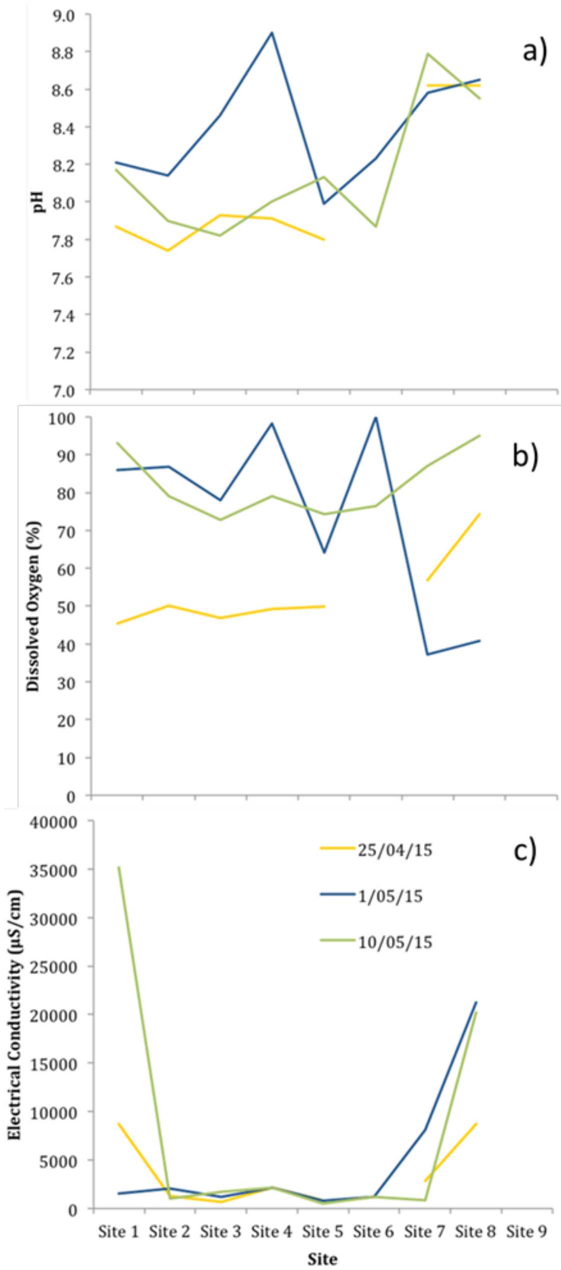

Fig. 3 Water quality data collected from 9 sites along Kororoit Creek in the winter of 2015. a) pH; b) dissolved oxygen; c) electrical conductivity.

In terms of pH, all samples were relatively similar, ranging from approximately 8.6 at the most upstream site (Site 8) to about 8.2 in the downstream sites. For all samples the pH was basic (above 7). The dissolved oxygen (DO) results were quite varied between sampling periods. DO was relatively low (~50%) for most sites on the first sample date (25/04). The following two dates returned higher values for most sites except for Sites 7 and 8, which neared 40% on 01/05/2015. Electrical conductivity was low for all dates for Sites 2 to 6 but varied considerably between samples for Sites 1, 7 and 8.

Table 1 Comparison between the data obtained for nine field sites along Kororoit Creek and the standards given by [11].

	Parameter guideline values			
	pH	TDS (ppm)	DO (%)	EC (μScm^{-1})
Sites	6.8 – 8.3	1000	85 – 110	500
1	X	X	X	X
2	✓	✓	X	✓
3	✓	✓	X	✓
4	X	X	X	X
5	✓	✓	X	✓
6	✓	✓	X	✓
7	X	X	X	X
8	X	X	X	X
9	-	-	-	-

Note: TDS = total dissolved solids; DO = dissolved oxygen; EC = electrical conductivity.

According to [11] guideline levels, the pH should be between 6.8 and 8.3. At sites 1, 4, 7 and 8 the pH exceeded guideline values (Table 1). Similarly, these four sites were outside guideline values for electrical conductivity, DO and total dissolved solids. All of the remaining sites were within guideline values for all of these variables except DO, with every site being deficient in oxygen relative to guideline levels for at least one sample. For each of these variables, there does not appear to be a clear and consistent link between land use type and water quality.

A total of 20 variables were measured over a period of 20 years at the two Melbourne Water monitoring sites. Generally speaking, variables of particular categories (such as metals and nutrients) behaved similarly between these two sites. For this reason, only representative plots are included in this paper and these were chosen to display the general pattern in variable levels at each site.

In terms of the standard water quality parameters of pH, DO and electrical conductivity, the results from the Melbourne Water sites tend to confirm the results from the field data with the downstream site (equivalent to field Site 1) exceeding guideline values for pH and electrical conductivity (but somewhat surprisingly not for DO) while the upstream site (equivalent to field Site 5) only exceeded guideline values for DO (Table 2).

Table 2 Comparison between the data obtained by Melbourne Water in two monitoring sites along Kororoit Creek and the standards given by [11].

Parameter	**Guideline Values**	**WBKO R0227**	**WBKO R0278**
pH	6.5 - 8.3	✓	X
Dissolved Oxygen (%)	85% - 110%	X	✓
Electrical Conductivity	500 μScm^{-1}	✓	X
Temperature	15 - 35 °C	X	X
Turbidity	10 NTU	✓	X
Suspended Solids	NR	-	-
NO_3	0.7 mg/L	✓	X
NO_2	NR	-	-
NH_3	0.9 mg/L	✓	✓
Total N	0.6 mg N L^{-1}	X	X
PO_4	0.02 mg P L^{-1}	✓	X
Total P	0.025 mg P L^{-1}	X	X
Escherichia Coli	NR	-	-
Arsenic	0.013 mg/L	✓	X
Cadmium	0.0002 mg/L	X	X
Chromium	0.001 mg/L	✓	X
Copper	0.0014 mg/L	X	X
Lead	0.0034 mg/L	✓	X
Nickel	0.011 mg/L	✓	X
Zinc	0.008 mg/L	✓	X

✓. The parameter is within the permitted levels; X. The parameter is not within the permitted levels; **NR.** No guideline recommended.

Fig. 4 presents data for two key nutrients, Total Nitrogen (TN) and Total Phosphorous (TP) for the two Melbourne Water sites. These data show that the downstream site was consistently higher than the upstream site for both of these key nutrients. This result demonstrates a clear link between nutrient concentrations and industrial land uses (as nutrient levels are low upstream in the residential area). These findings are consistent with previous research that has shown that nutrient levels can increase in industrial areas. However, it is important to mention that the results are contrary to previous investigations that have found nutrient levels to be high in agricultural areas [14].

This result may be related to the distance between the furthest upstream monitoring site

(WBKOR0227) and the agricultural zone (which is several km upstream) or to a relatively low fertilization regime in the agricultural areas of Kororoit Creek. To confirm whether nutrient pollution is not a problem upstream, it is recommended that an additional long term water quality monitoring site be added in this area to complement those already available. In any case, it is clear that the residential areas of Kororoit Creek do not contribute significant quantities of nutrients to the stream but industrial areas do.

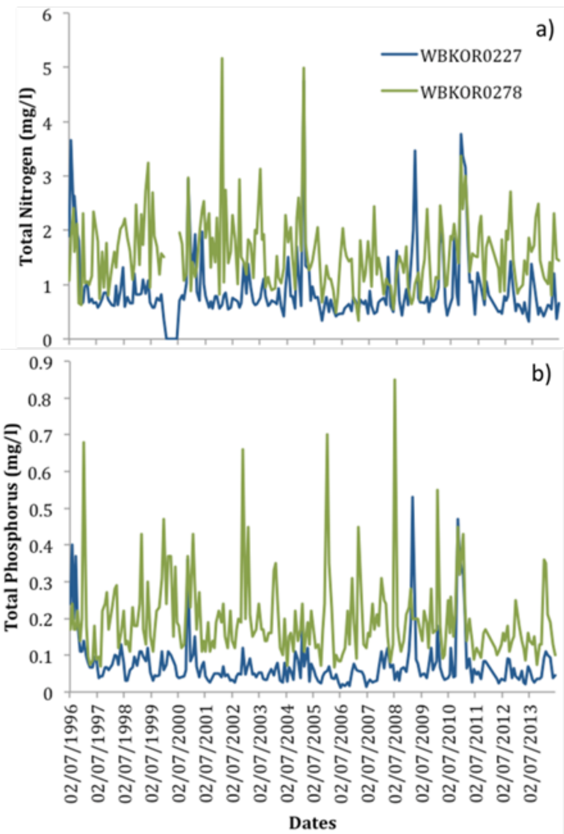

Fig. 4 Nutrient data from Melbourne Water quality assessment sites. a) total nitrogen; b) total phosphorus.

The downstream site also consistently displayed higher metal concentrations than the upstream site (Fig. 5). These results suggest that the industrial zone is a major source of metals to the river system while the residential area is not. These results are consistent with previous research. For example, [12] accredited the presence of heavy metals to factories in and around urban rivers, a pattern that is also reflected in this study. Hence, both nutrients and metals seem closely linked to industrial land uses.

In contrast, the upstream site displayed higher concentrations of E. Coli (Fig. 6) than the downstream site. In this case, then the source of E. Coli appears to be residential land uses. In these types of regions, one of the main water quality threats is the discharge of faecal matter, which is a primary contributor to E. Coli levels [13]. In contrast, the downstream site is situated in a predominantly industrial area, and so is unlikely to have a ready source of faecal matter that would cause elevated levels to be present there. Thus, for E. Coli there appears to be a clear link between land use and pollutant load, with residential areas generating high E. Coli levels and industrial areas generating low E. Coli levels.

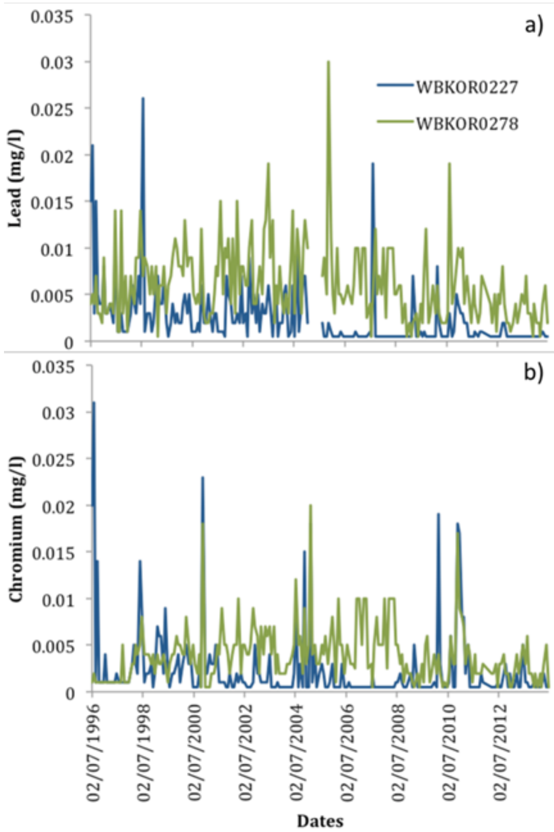

Fig. 5 Metal data from Melbourne Water quality assessment sites. a) lead; b) chromium.

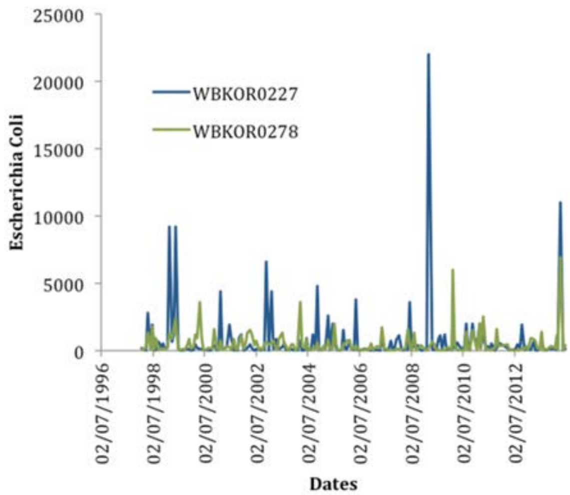

Fig. 6 E. Coli data from Melbourne Water quality assessment sites.

The performance of all of the parameters monitored by Melbourne Water against [11] guideline levels are presented in Table 2. These data show that for nearly every variable (the exceptions being NH_3 and DO) the downstream site breaches [11] guidelines, indicating that the river is extensively polluted at its outlet. However, the river is in relatively good condition further upstream with only six variables (DO, temperature, total nitrogen, total phosphorus, cadmium and copper) regularly exceeding guideline levels. A current focus on tree planting in the upstream reaches should help to improve these values even further, resulting in a relatively safe and healthy upstream riverine environment. However, there appears to be little prospect of improved water quality downstream unless the adjacent industries are encouraged or compelled to reduce their discharges to the creek.

5. CONCLUSIONS

The results of this study reveal a strong relationship between water quality and land use. Of the land uses investigated in this research, industrial areas are by far the biggest contributors to poor water quality, with nutrients and metals being especially high in and around these areas. In contrast, residential water quality was relatively good, although elevated levels of E. Coli could be found in these areas. It is hoped that a current wave of tree planting along the banks in the residential areas will help to improve the water quality in these parts of the river further in coming years. However, it is unlikely that the water quality in the industrial areas will improve without a concerted effort to reduce the flow of pollutants into the river from the surrounding industries.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Mouri, G. (2015). Assessment of land cover relocation incorporating the effects of human activity in typical urban and rural catchments for the design of management policies. Env. Sci. and Policy, 50, 74-87.

[2] Spänhoff, B., Dimmer, R., Friese, H., Harnapp, S., Herbst, F., Jenemann, K., Müller, U. (2012). Ecological status of rivers and streams in Saxony (Germany) according to the water framework directive and prospects of improvement. Water (Switzerland), 4, 887-904.

[3] Rezaei, A., & Sayadi, M. (2015). Long-term evolution of the composition of surface water from the river Gharasoo, Iran: A case study using multivariate statistical techniques. Env. Geochem. and Health, 37, 251-261.

[4] Choi, J. Lim, K. & Won, C. (2013). Catchment water quality management planning for sustainable development of tidal areas. Irrig. and Drain., 62, 18-23.

[5] Yan, C., Zhang, W., Zhang, Z., Liu, Y., Deng, C., & Nie, N. (2015). Assessment of Water Quality and Identification of Polluted Risky Regions Based on Field Observations & GIS in the Honghe River Watershed, China. Plos ONE, 10, 1-13.

[6] Kai, D., Jianguo, W., Jianqiang, W., Wang, C., Changjun, Z., & Xiaoyan, W. (2015). Treatments to Control Urban River Pollution in Water Source City of South to North Water Diversion Project. Polish J. of Env. Stud., 24, 501-504.

[7] Matysik, M., Absalon, D., & Ruman, M. (2015). Surface water quality in relation to land cover in agricultural catchments (Liswarta river basin case study). Polish J. of Env. Stud., 24, 175-184.

[8] Leščešen, I., Pantelić, M., Dolinaj, D., Stojanović, V., & Milošević, D. (2015). Statistical Analysis of Water Quality Parameters of the Drina River (West Serbia), 2004-11. Polish J. of Env. Stud., 24, 555-561.

[9] Rai, U., Upadhyay, A., Singh, N., Dwivedi, S., & Tripathi, R. (2015). Seasonal applicability of horizontal sub-surface flow constructed wetland for trace elements and nutrient removal from urban wastes to conserve Ganga River water quality. Eco. Eng., 81, 115-122.

[10] Valle Junior, R. F., Varandas, S., Pacheco, F., Pereira, V., Santos, C., Cortes, R., & Sanches Fernandes, L. (2015). Impacts of land use conflicts on riverine ecosystems. Land Use Policy, 43, 48-62.

[11] ANZECC / ARMCANZ, 2000, 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Vol 1.

[12] Dumas, C., Ludwig, W., Aubert, D., Eyrolle, F., Raimbault, P., Gueneugues, A., & Sotin, C. (2015). Riverine transfer of anthropogenic and natural trace metals to the gulf of lions (NW mediterranean sea). App. Geochem., 58, 14-25.

[13] Titilawo, Y., Obi, L., & Okoh, A. (2015). Antimicrobial resistance determinants of escherichia coli isolates recovered from some rivers in osun state, south-western nigeria: Implications for public health. Sci. Total Env., 523, 82-94.

[14] Ahearn, D., Sheibley, R., Dahlgren, R., Anderson, M., Johnson, J., & Tate, K. (2005). Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. J. of Hyd., 313, 234-247.

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